Damage Detection Sensor System for Aerospace and Multiple Applications

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Agenda

- Background
- Technology
- System Design
- Testing and Demonstration
- Implementation Approaches
- Summary and Conclusions
- Questions

Background

- NASA has identified structural health monitoring and damage detection and verification as critical needs for Space Exploration in multiple technology roadmaps

- Micrometeoroids (MM) & Orbital Debris (OD) impacts continue to be serious threats to the International Space Station (ISS), commercial crew vehicles and extraterrestrial habitats

  - NASA classifies MM & OD as primary threats to commercial crew vehicles
    - See article at https://www.nasaspaceflight.com/2016/08/nasa-mmod-primary-threat-crew-vehicles/

  - In July 2014, radiator damage to the ISS was observed after review of downlinked camera inspection imagery
    - See article at http://www.nasaspaceflight.com/2014/07/iss-managers-evaluating-mmod-radiator/)

Background (Continued)

- NASA Kennedy Space Center (KSC) has been designing and developing damage detection technologies for years, including those for electrical wiring and flat surfaces
  - Patents awarded **US9,233,765** and **US9,635,302,B2**

- KSC has successfully tested and demonstrated damage detection technologies
  - In 2011, demonstrated a single panel system for Habitat Demonstration Unit (HDU) field demonstration at Desert Research and Technology Studies (D-RATS)
  - In 2012, integrated and demonstrated a multiple sensory panel damage detection system in the crew display avionics for HDU at Johnson Space Center (JSC)
  - In 2013, demonstrated remote testing capability of a three panel system using a secure network (between KSC & JSC)

Damage Detection Technology

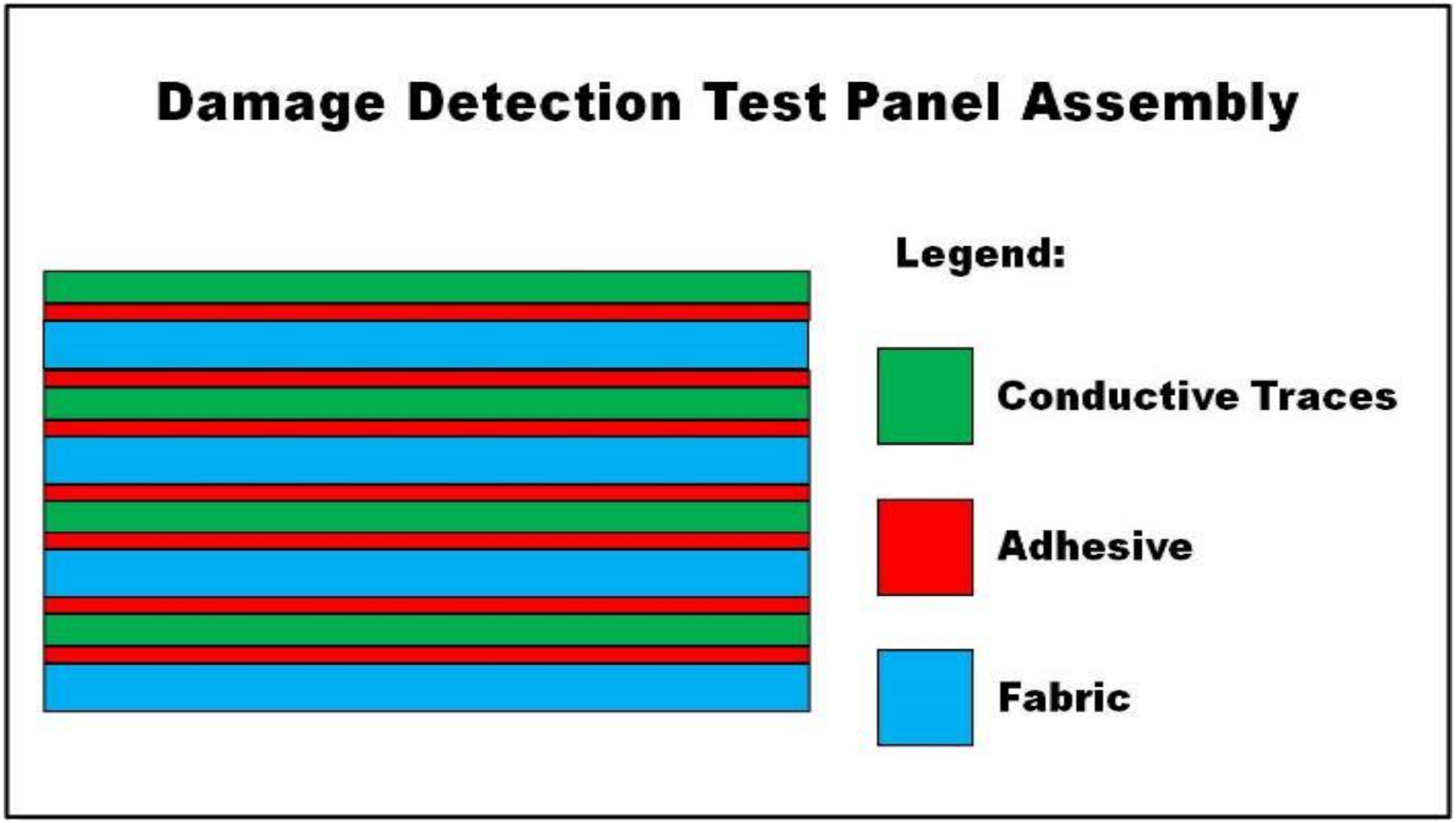
- Based on sensing the electrical integrity of parallel conductive traces
  - When an impact occurs, traces are broken
- Several sensing layers can be implemented, where alternate layers are arranged orthogonally with respect to adjacent layers
  - Estimates damage size and pinpoints damage location
  - Multiple detection layers allow for the calculation of the depth of the damage
- Minimizes the use of active electronic components
  - Low power consumption – typical application less than 5W
- Design is tailorable for interior and/or exterior applications, embedded or additional
  - Sensing panel material, size, and conductive trace spacing can be customized per application

System Design

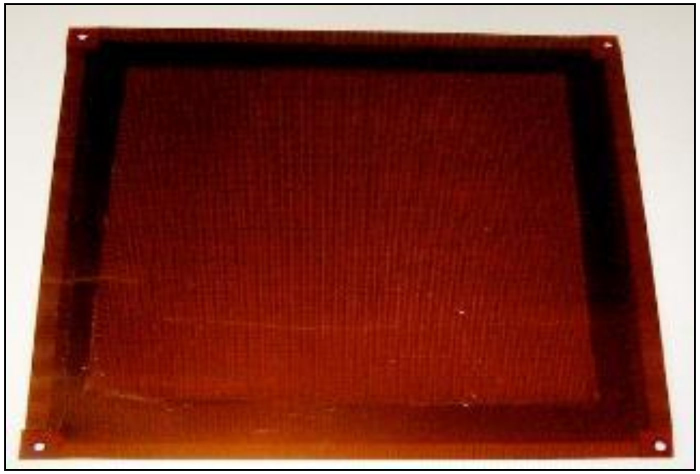
- Consists of three main custom designed subsystems
  - Multi-layer sensory panel
    - Current configuration has four layers
    - Constructed of Kapton® with Kevlar ® or Buna-N rubber for demonstration purposes
  - Embedded monitoring system
    - Microcontroller injects & monitors test signals to determine the electrical integrity of the sensing traces
    - Wirelessly transmits telemetry to a laptop with the GUI
  - Graphical User Interface (GUI)
    - Developed in National Instruments LabVIEW software
    - Sends commands and receives telemetry from the embedded monitoring system
    - Processes the telemetry and calculates damage characteristics, such as the damage size, the penetration depth, and the damage location using custom-developed algorithms

System Design – Sensory Panel Layup

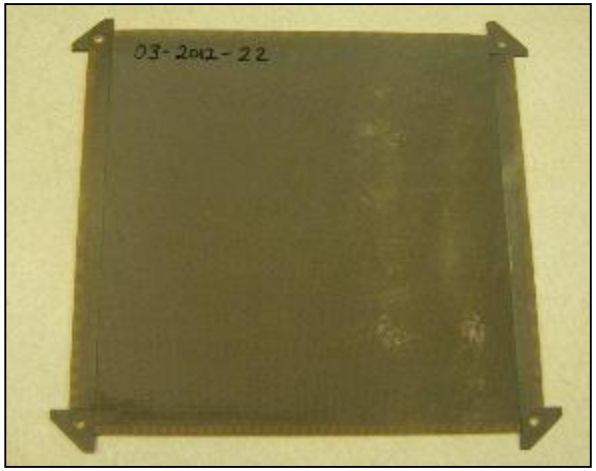
- Designed to simulate a multi-layered architecture
- Prototypes are designed to be durable and withstand harsh environments



System Design – Sensory Panel Fabrication

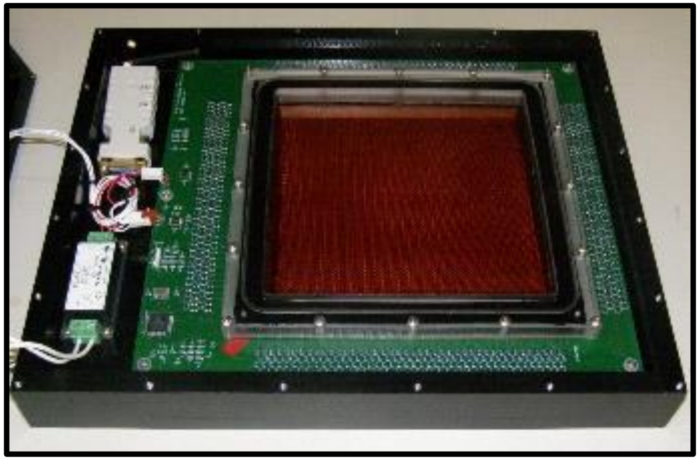


Insulation side of laboratory (left) and commercially (right) printed circuitry

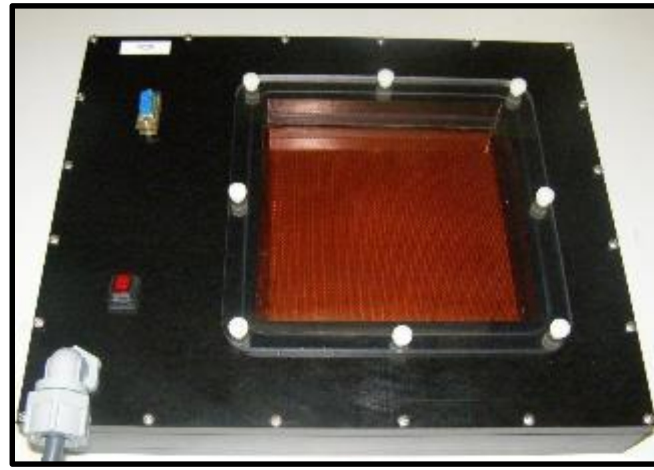


Fabric side of laboratory printed and assembled multi-layered system (left) and commercially (right) printed circuitry and laboratory assembled multi-layered system (right)

System Design – Enclosure Fabrication

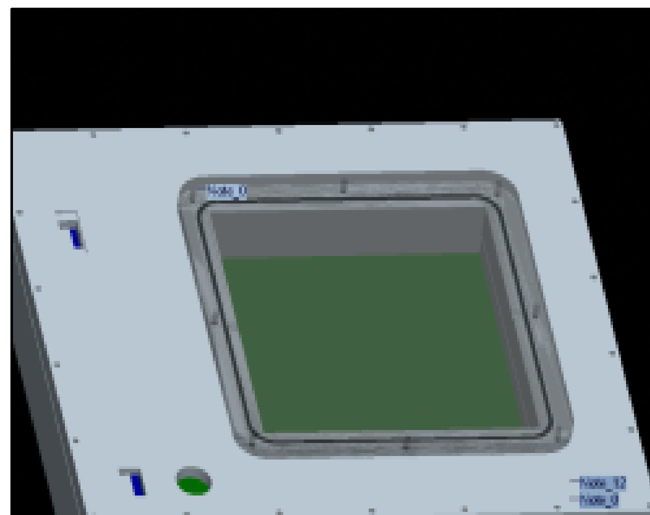


Inside view sensory system in enclosure



Outside view of sensory system and enclosure

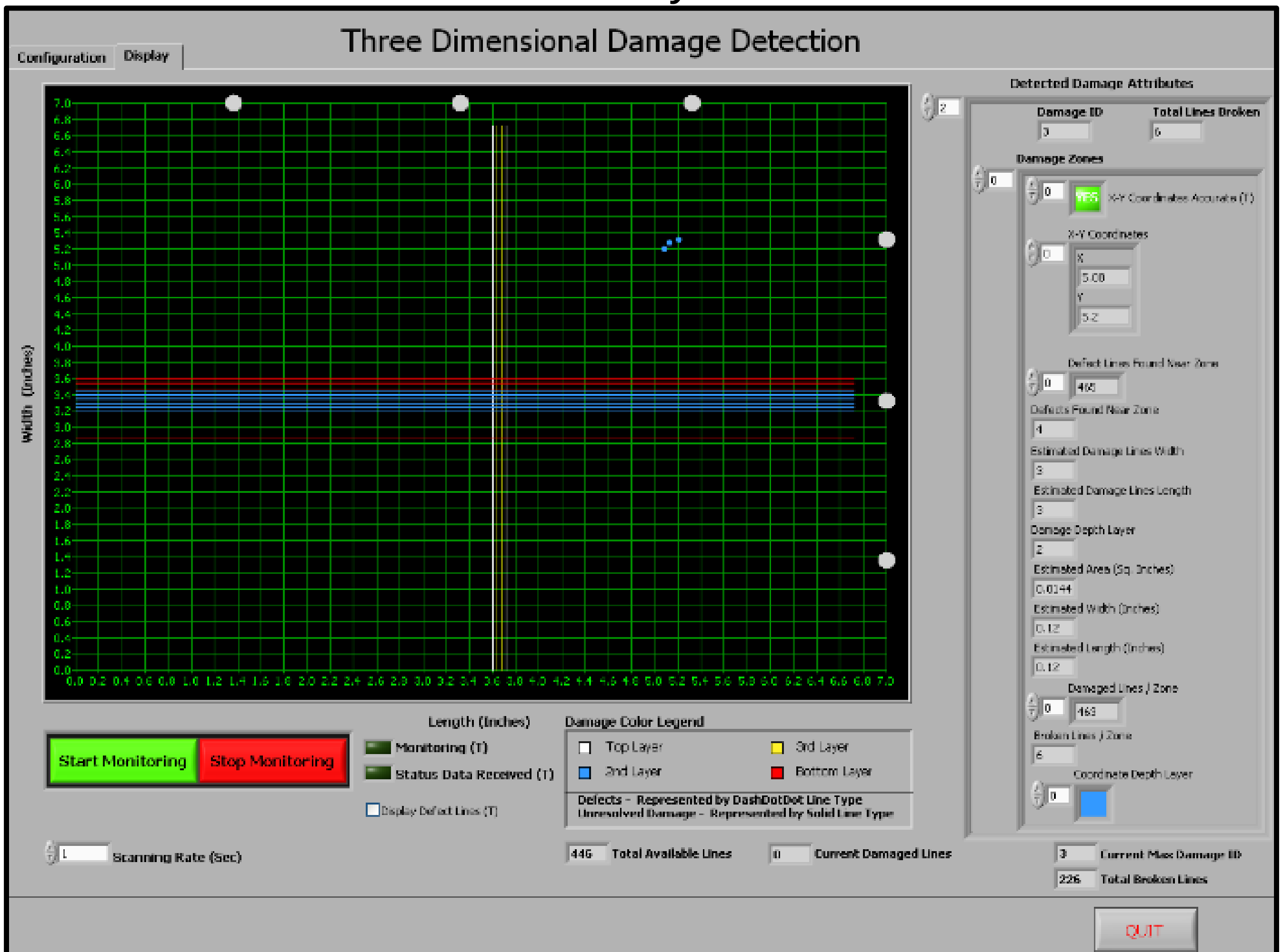
Close-up of damaged areas performed on sensory panel

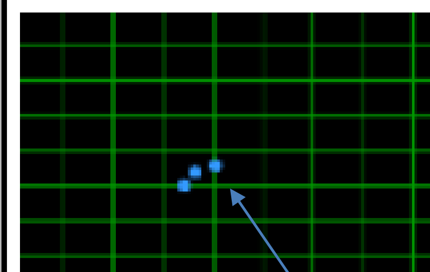


Pro-E model of 3-D printed sensory system enclosure

System Design – GUI

- Example of GUI interface
- Color coded to indicate multi-layer resolution





Damage zone to the second layer

Damage zone all layers

Testing and Demonstration

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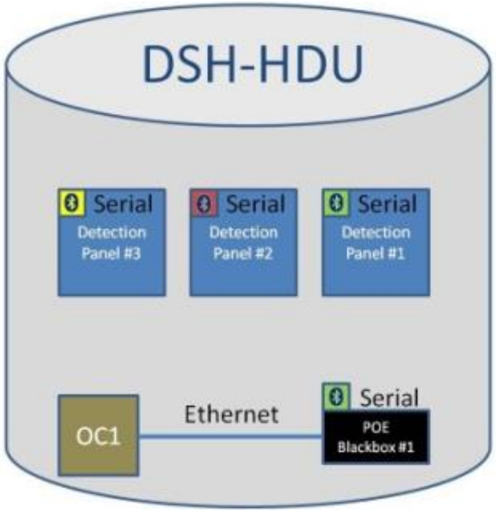
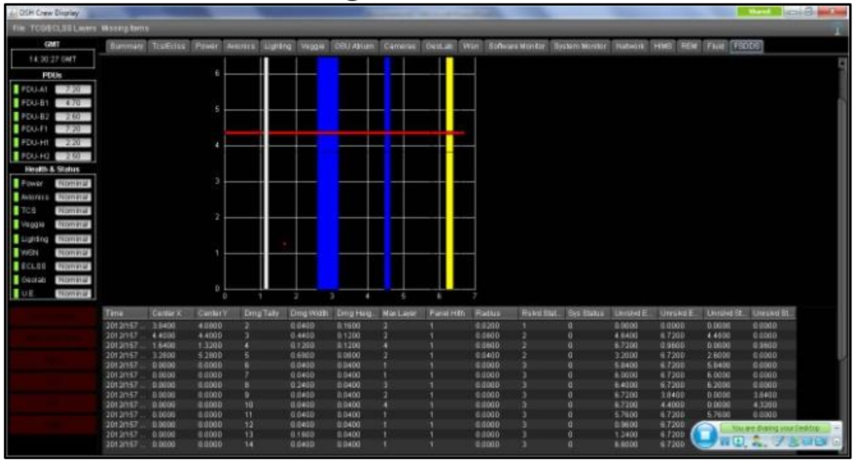
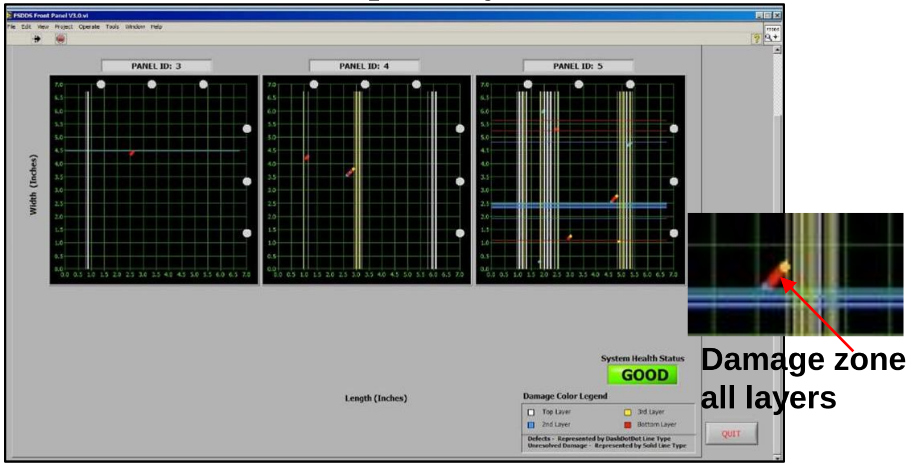
Multiple Sensory Panels with Habitat Demonstration Unit (HDU) and Missions Operations Test (MOT) Analog Demonstration



Block Diagram Pictorial Representation of the Communication Layout of the FSDDS Stand-Alone and Multi-panel Systems



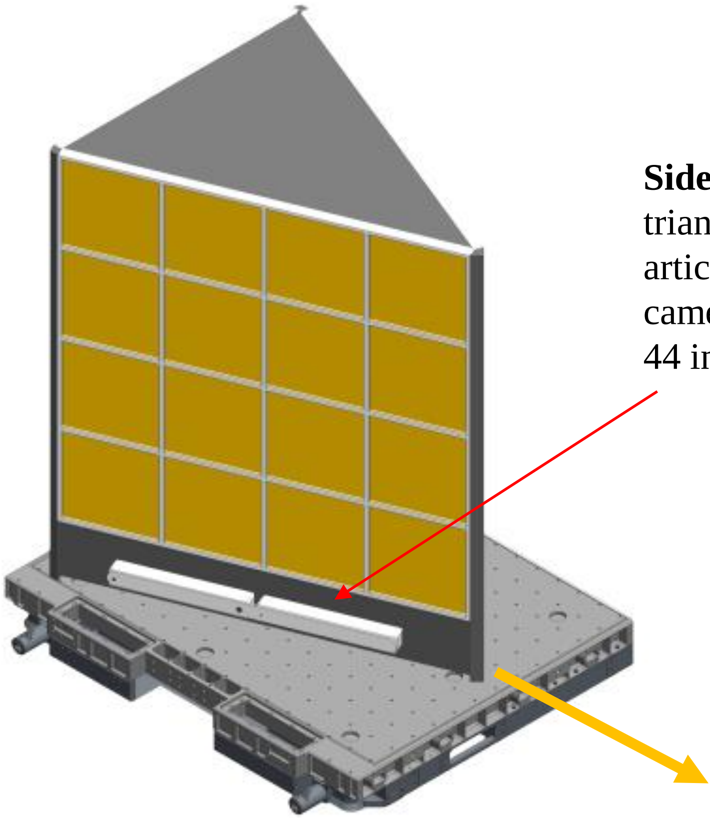
Avionic crew display during demo testing



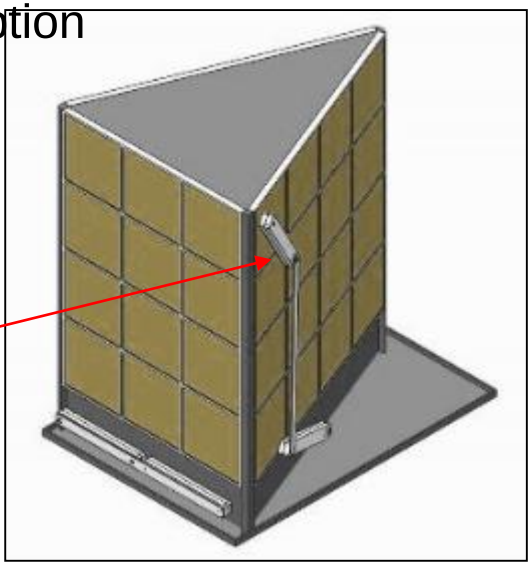
3 sensory panels during remote integration testing

Implementation Approaches

- Used predictive modeling tools Orbital Debris Engineering Model (ORDEM 3.0) and Meteoroid Engineering Model (MEM)
- Developed custom mathematical simulator tool to design and model a three-sided architectural design layout for flight experiment option



Side and Rear Views: triangular layout with articulated arms for cameras and total of 44 individual panels



RAM Direction

Implementation Approaches

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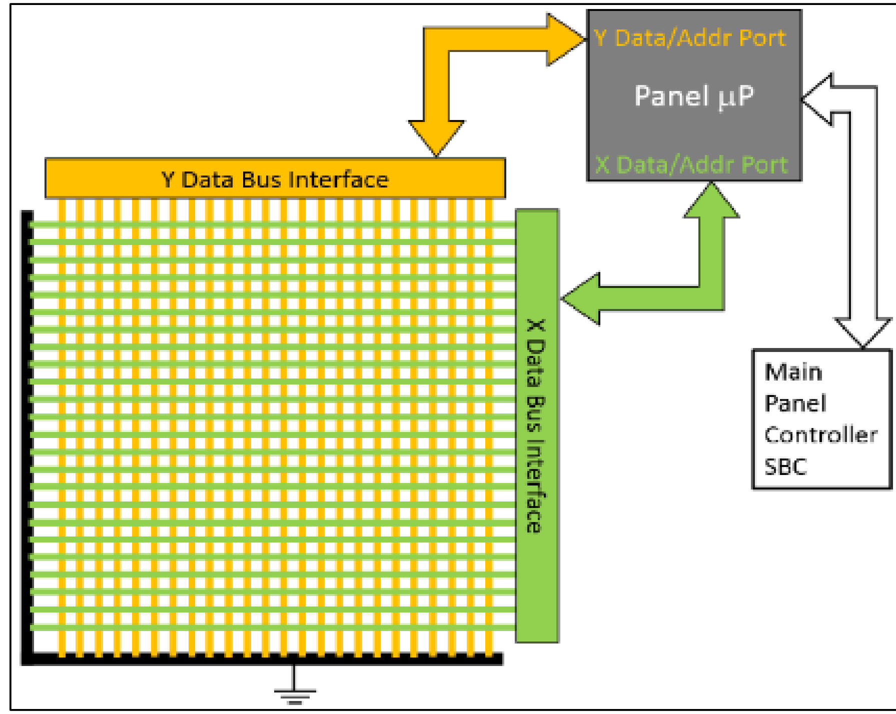
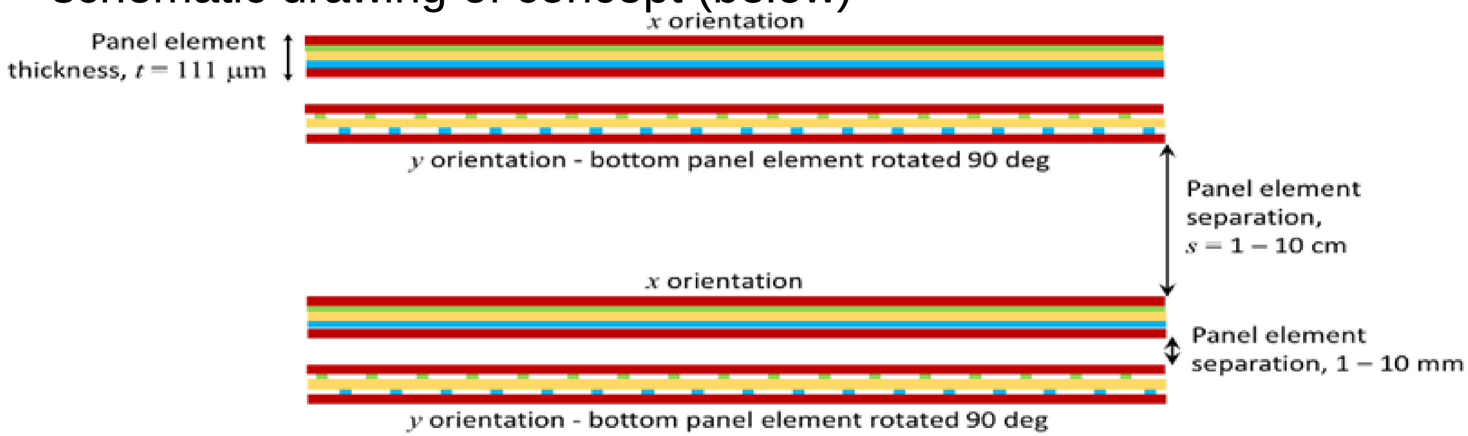
Design considerations:

- based on mathematical simulator, design for flight experiments could include multiple sensory panels with single board controllers (SBC) and data BUS interfaces for maximum area coverage and monitoring of impact damage due to space debris.
- schematic drawing of concept (left).
- optional designs can also include capability for calculating velocity and trajectory.
- schematic drawing of concept (below)





Summary

- NASA has identified structural health monitoring and damage detection and verification as critical needs in multiple technology roadmaps.

- The sensor systems can be customized for detecting location, damage size, and depth, with velocity options and can be designed for particular environments for monitoring of impact or physical damage to a structure.

- The damage detection system has been successfully demonstrated in a harsh environment and remote integration tested over 1000 miles apart.

- Multiple applications includes: Spacecraft and Aircraft; Inflatable, Deployable and Expandable Structures; Space Debris Monitoring; Space Habitats; Military Shelters; Solar Arrays, Smart Garments and Wearables, Extravehicular activity (EVA) suits; Critical Hardware Enclosures; Embedded Composite Structures; and Flexible Hybrid Printed Electronics and Systems.

- For better implementation and infusion into more flexible architectures, important and improved designs in advancing embedded software and GUI interface, and increasing flexibility, modularity, and configurable capabilities of the system are currently being carried out.

- NASA Tech Brief Create the Future Contest 2016 Top 100 Entries https://contest.techbriefs.com/2016/entries/aerospace-and-defense/6876; feature article https://issuu.com/spaceportmagazine/docs/spaceport_magazine_____april_2017/34

Questions??

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Technology featured at NASA Technology Transfer T2 Booth #323

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